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OFFICE OF CHEMICAL SAFETY
AND POLLUTION PREVENTION

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MEMORANDUM

SUBJECT: Assessment of the Benefits of Dicamba Use in Genetically Modified, Dicamba-Tolerant Cotton Production

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SUMMARY

This document describes the benefits of registering dicamba for preemergence and postemergence use on dicamba-tolerant (DT) cotton. $6.6 billion worth of cotton is grown annually on 9.3 million acres each year in the United States. In 2017 and 2018, growers used dicamba on 17% of all U.S. cotton acres (DT and non-DT) prior to crop emergence and on 34% of all U.S. cotton acres after crop emergence. Postemergence dicamba is primarily used to target herbicide-resistant Palmer amaranth and redroot pigweed but is effective at controlling a range of broadleaf weed species.

The dicamba-tolerant system was created to address weed populations with resistance to glyphosate (Weed Science Society of America [WSSA] Group 9 herbicide), ALS (acetolactate synthase) inhibitor herbicides (WSSA Group 2) and PPO (protoporphyrinogen oxidase) inhibitor herbicides (WSSA group 14). The registration of dicamba in DT cotton would give growers additional flexibility in choosing varieties for managing herbicide-resistant weed populations, thereby prolonging the effectiveness of currently available control options for herbicide-resistant weed species. For areas where dicamba products cannot be used on DT cotton, there are effective alternative weed control programs currently available for the control of problematic broadleaf weeds in cotton. However, the number of postemergence herbicide options is very limited; therefore, many cotton growers can benefit from the registration of dicamba for use in DT cotton.

In addition to postemergence application, dicamba in DT cotton has utility prior to crop emergence. Currently registered dicamba formulations include a preplant restriction of a specified number of days and amount of rainfall accumulation between dicamba application and planting to avoid cotton injury. Since DT cotton is highly tolerant of dicamba, the dicamba products intended for use on DT cotton do not include such preplant restrictions, meaning that they can be used at any time up to cotton planting, thereby increasing the flexibility for preemergence dicamba use. This increased flexibility of preemergence use of dicamba on DT cotton is another benefit of the registration of these dicamba products.

Relative to other alternative herbicide programs, a postemergence dicamba program may reduce grower costs by $8-$14 per acre, which may account for 5-10% of grower net operating revenue. Seed costs and rebates offered by seed and chemical manufacturers can vary widely and affect the overall cost of the herbicide program.

In addition, the further development of dicamba-resistant weed populations would reduce the benefits of this technology in areas where dicamba resistant populations emerge. For example, additional herbicide applications may be necessary to achieve adequate weed control where species are experiencing decreased susceptibility to dicamba, increasing the cost of the postemergence dicamba program relative to alternative herbicide programs. Dicamba-resistant Palmer amaranth have been confirmed in two states. Furthermore, antagonism between glyphosate and antagonism may require growers facing pressure from grass weeds to make additional passes through the field. Risk control measures, discussed in *Dicamba Use on Genetically Modified Dicamba-Tolerant (DT) Cotton and Soybean: Incidents and Impacts to*

Users and Non-Users from Proposed Registrations (Chism et al., 2020), may also impinge on the benefits of dicamba, depending on the measure itself.

Overall, BEAD concludes that the registration of dicamba for preemergence and postemergence use in DT cotton gives many growers increased flexibility in their choice of seed varieties. Growers using DT seed have the option to use dicamba as a cost-effective way to control problematic herbicide-resistant broadleaf weed species, and as an additional tool to delay the further development of herbicide resistance.

INTRODUCTION

The Federal Insecticide Fungicide and Rodenticide Act (FIFRA) Section 3(c) mandates that the Environmental Protection Agency (EPA or Agency) evaluate applications for the registration of a pesticide to ensure that it does not pose unreasonable adverse effects to human health and the environment. In determining whether effects of pesticide use are unreasonable, FIFRA requires that the Agency consider the risks and benefits of any use of the pesticide.

The Agency has completed risk assessments to inform the registration of dicamba that is applied to DT cotton after cotton emergence. This type of application is also called a postemergence application and refers to the herbicide being applied to the emerged DT cotton to remove existing weeds in the crop (also referred to as "Over the Top" or OTT use). This use differs from traditional (pre-DT cotton) dicamba use in cotton, which was restricted to preplant use only.

The Agency registered three postemergence dicamba products for use on genetically modified herbicide-resistant cotton in 2016 (Engenia, EPA Reg. No. 7969-345; Fexapan, EPA Reg. No. 352-913; Xtendimax with Vaporgrip Technology, EPA Reg. No. 524-617). These postemergence dicamba products were granted an extension of registration on October 31, 2018 (EPA, 2018e) with modifications to the registrations. The registrations of these three products were vacated on June 3, 2020, by the United States Court of Appeals for the Ninth Circuit (*National Family Farm Coalition, et. al. v. EPA*, 960 F.3d 1120 (9^{th} Cir. 2020). On April 5, 2019, EPA registered a product containing a combination of dicamba and S-metolachlor for postemergence use on dicamba-tolerant cotton and soybeans (Tavium EPA Reg. No. 100-1623). This combination of active ingredients was previously an approved tank mix, and as such, was already used postemergence on cotton and soybeans. The registration for this dicamba product is set to automatically expire on December 20, 2020. EPA is currently considering applications for registration of dicamba products for preemergence and postemergence use on DT soybean and cotton for the 2021 growing season.

This memorandum assesses the general benefits of preemergence and postemergence use of dicamba on DT cotton, as well as alternative to postemergence use of dicamba on DT cotton, to inform the final registration decision. This assessment also presents information on the historical usage of dicamba in DT cotton, including data and information on the percentage of acreage treated, application timings, and target pests. This memorandum is one in a series that address the use of dicamba in DT cropping systems that are available in the docket. The usage, alternatives, and benefits of preemergence and postemergence dicamba in soybean are discussed in *Assessment of the Benefits of Dicamba Use in Genetically Modified, Dicamba Tolerant*

Soybean Production (Orlowski and Kells, 2020). The impact of potential control measures for preemergence and postemergence dicamba in cotton and soybean are discussed in *Dicamba Use on Genetically Modified Dicamba-Tolerant (DT) Cotton and Soybean: Incidents and Impacts to Users and Non-Users from Proposed Registrations* (Chism et al., 2020).

METHODOLOGY

BEAD qualitatively assessed the benefits of preemergent dicamba use in DT cotton and quantitatively assessed the benefits of postemergence dicamba use in DT cotton by comparing grower outcomes with the use of dicamba in DT cotton to grower outcomes with the use of existing alternative herbicide control programs. The unit of analysis for this assessment is an acre of DT cotton that would likely be treated with dicamba. BEAD assessed the benefits of dicamba use in DT cotton on a national average per-acre basis. Dicamba for use in DT cotton was initially registered in late 2016 and data on dicamba usage from a private market research firm are available for this comparison. Data on use of DT seed and dicamba use are available from 2017-2018; data on the use of alternative herbicides are available from 2014-2018.

BEAD first identifies the primary weeds targeted by growers when using postemergence dicamba. Data for this purpose comes from state agricultural Extension services, primary peer-reviewed literature publications and pesticide market research data, collected through annual surveys of growers conducted by a leading private research firm (Kynetec, Inc.). The surveys provide representative, statistically valid data with which to draw conclusions about grower use of herbicides and seed trait adoption. BEAD identifies alternative herbicide control programs using market research data and data from state agricultural Extension agencies combined with the professional judgment of BEAD agronomists and agricultural economists based on biological considerations (e.g., similar or improved weed control, herbicide resistance management) and economic considerations (e.g., lower costs, including non-monetary costs such as managerial effort). BEAD collects information on herbicide costs from pesticide market research data (Kynetec, 2019) and data from the performance of alternative herbicides on important weed species for dicamba from published Extension weed control recommendations.

BEAD then considers differences in weed control cost per acre and/or revenue per acre in the context of grower income to characterize the potential benefits of postemergence dicamba in cotton. BEAD uses net operating revenue, defined as gross revenue per acre less operating costs per acre, as the measure of income. Data from the U.S. Department of Agriculture (USDA) National Agricultural Statistics Service (NASS) are used to calculate average gross revenue per acre; data from Texas A&M University (TAMU) Extension provide estimates of production costs. Fixed costs, such as land rent, equipment depreciation, and overhead costs, although estimated by TAMU, are not included because allocating these costs on a per acre basis is complex due to the variation in farm size and diversity in farm production. Moreover, fixed costs are often not included in crop budgets produced by other organizations. For consistency across use sites, BEAD relies on measures of net operating revenue, acknowledging that this overstates grower income per acre by not accounting for fixed costs and will underestimate the potential per-acre benefit of pesticide use. By assessing the benefits of dicamba on a per-acre basis, BEAD's conclusions about the benefits of dicamba are independent of BEAD's estimates of total dicamba usage, and therefore are not impacted by over- or undercounting of dicamba usage.

BACKGROUND

Previous EPA Assessments of the Benefits of Registering Postemergence Dicamba

In 2016, BEAD assessed the benefits of dicamba intended for use in DT crops using registrant claims, and found that the main benefit of postemergence OTT dicamba was that it provided DT soybean and cotton growers with another active ingredient to manage difficult to control broadleaf weeds during the crop growing season, especially glyphosate-resistant weeds (Yourman and Chism, 2016).

The Agency again assessed the benefits of dicamba intended for use in DT crops production in 2018 (EPA, 2018d). The 2018 assessment found that the registration of postemergence dicamba provided growers with an additional active ingredient to manage problematic broadleaf weeds, especially for situations where herbicide-resistant populations of these weeds are known to occur. The 2018 assessment also found that the registration of postemergence dicamba provided a long-term benefit as a tool to delay the evolution of resistance in weed species to other herbicides when used as part of a season-long weed management program. Since the release of the 2018 assessment, dicamba-resistant Palmer amaranth has been confirmed in two cotton-producing states; see section below titled "Dicamba Resistance in Dicamba Target Weeds." As dicamba resistance in target weed species is expected to spread, the benefits of dicamba in DT cotton will be lower than those assessed in 2018, although the decreased benefits will be concentrated in areas where dicamba-resistant broadleaf weed species are established.

In 2019, EPA also assessed the benefits of another dicamba product, a pre-mix of dicamba and S-metolachlor (Tindall, 2019). EPA found no unique benefits to the product not discussed in the 2018 assessment.

Registrant Submission of Information Regarding the Benefits of Registering Dicamba for Use on DT Cotton

In 2020 Bayer submitted a document to EPA in support of the registration of postemergence dicamba (Bayer, 2020). This document states that dicamba is useful as an additional mode of action to combat herbicide-resistant weeds. Bayer also suggests that in the absence of postemergence dicamba growers who face herbicide-resistant weeds may be forced to use more expensive and less effective alternatives, which may decrease grower revenues and result in yield loss. The document also states that some weed control alternatives, such as tillage, may have a negative impact on the environment. The document suggests that postemergence dicamba, when used as part of a soil residual and postemergence weed management program, can help mitigate the potential for the development of weed resistance to other herbicides. Bayer suggests that the absence of postemergence dicamba may result in overuse of remaining postemergence herbicide modes of action and thus may increase selection pressure in problematic weed species for resistance to these herbicides.

Letters Describing the Benefits of Postemergence Dicamba

While there was no public comment period for the 2018 or pending 2020 dicamba registration decisions, the Agency has received several letters concerning the pending dicamba registrations for use with DT cotton and soybean. For a summary of comments and a list of commenters see Chism et al. (2020). Information from the submitted letters are incorporated, as appropriate, in this assessment, the benefits assessment for soybean (Orlowski and Kells, 2020) and the impacts assessment (Chism et al., 2020).

WEED MANAGEMENT IN COTTON

Weeds compete with cotton for limited resources such as space, nutrients, moisture, and may serve as reservoirs or hosts for insect pests and/or pathogens. To effectively manage weeds in fields producing cotton, growers rely on several management tactics that can include tillage, cultivation, and herbicides. Hand weeding is usually not economically feasible for cotton and cultivation is rarely practiced due to the relatively slow speed of cultivation operations compared to herbicide application, and soil erosion concerns. Herbicides allow growers to avoid many of these non-chemical management costs and allow for the utilization of conservation tillage. While herbicides are the primary means of weed control in cotton, growers must consider multiple factors (e.g., timing, weed targets, resistance management, label restrictions) when making herbicide selections.

The goal of a cotton herbicide program is to plant cotton into weed-free conditions and maintain a weed-free period until the cotton reaches canopy closure. Weeds can be removed prior to planting using conventional tillage practices or with non-selective herbicides as part of a burndown herbicide program. Depending on the weed species present and the weed pressure in the field, preemergence residual herbicides are used to control or suppress weeds during early-season cotton growth. Eventually, the residual activity of preemergence herbicides begins to decline and weeds emerge from the soil, requiring postemergence herbicide application. Foliar-applied herbicides are likely necessary to remove emerged weeds. An herbicide with residual activity is often applied along with the foliar-applied herbicide to control or suppress weeds until cotton canopy closure occurs.

Before the development of herbicide-tolerant cotton, common postemergence weed control in cotton relied on ALS inhibitor herbicides (WSSA Group 2) and postemergence-directed sprays utilizing herbicides such as fluometuron (WSSA Group 7). However, after the introduction of glyphosate-resistant cotton in 1997, glyphosate rapidly became the most widely used postemergence herbicide used in cotton. Glyphosate's broad-spectrum weed control and ease of use on glyphosate-tolerant cotton resulted in cotton producers using repeated applications to control weeds. Repeated applications of a single herbicide to the same weed species, such as Palmer amaranth, selected for individuals within the population with resistance to glyphosate. These resistant biotypes rapidly became the dominant biotype in a field, as would be expected for herbicide resistant weed species, rendering glyphosate ineffective as an herbicidal control measure for these species. As control with glyphosate failed, other classes of herbicides were used for postemergence control of glyphosate-resistant weeds. Eventually problematic weeds, such as Palmer amaranth, developed resistance to these herbicides as well, resulting in weed populations with resistance to multiple herbicide modes of action and necessitating the development of novel herbicide control measures. However, no new herbicide modes of action have been developed for use in cotton in over 30 years. In lieu of new modes of action, companies have focused on developing novel herbicide-tolerant cotton varieties that are tolerant to existing herbicides, like dicamba, that traditionally could not be applied postemergence to cotton (Heap and Duke, 2017).

CHEMICAL CHARACTERISTICS

Dicamba is an herbicide in the benzoic acid chemical family. The Weed Science Society of America (WSSA) has classified dicamba as a Group 4 synthetic auxin type herbicide. Dicamba is primarily used to control broadleaf weeds, where it mimics the function of endogenous auxin. Dicamba induces cell wall elongation and increases in RNA, DNA, and protein biosynthesis leading to uncontrolled cell division that eventually results in plant death. Dicamba also induces ethylene production in the plant which is thought to cause the leaf cupping and epinastic bending symptoms seen in susceptible plants exposed to dicamba. Dicamba is a systemic herbicide and uptake occurs primarily through foliage. Due to its systemic activity, dicamba is most effective when applied to actively growing weeds and control is best when applied to small weeds. Dicamba was first registered in the U.S. in 1967 and has been used in extensively in both crop and non-crop areas ever since (Shaner, 2014).

CROP PRODUCTION INFORMATION

Average acres harvested, production, and value of cotton are shown in Table 1 by production regions based on those defined by the National Cotton Council (NCC, 1996). Nationally, about 9.3 million acres of cotton are harvested per year, on average, producing 16.4 million 480-pound bales of cotton lint and 5.1 million tons of cottonseed, valued at around $6.6 billion (USDA/NASS, 2020). USDA's Economic Research Service (ERS) (2020b) describes cotton as one of the most important textile fibers in the world, accounting for around 25% of total world fiber use. The U.S. is the world's third-largest cotton producer and the leading cotton exporter, accounting for one-third of global trade in raw cotton. The U.S. cotton industry accounts for more than $21 billion in products and services annually, generating more than 125,000 jobs in the industry sectors from farm to textile mill. This does not include other jobs that may be created further in the supply chain (NCC, 2020a).

Most cotton production occurs in the Plains region, especially in Texas (USDA/NASS, 2020). High-value Pima cotton production is concentrated in the West region and does not occur in the Southeast or Mid-South (USDA/NASS, 2020). National cotton yields for 2013-2018 averaged just under two 480-pound bales of cotton lint and 0.55 tons of cottonseed per acre (Table 1). Average gross returns are around $710 per acre nationally and vary between $550 per acre in the

Plains to $1,060 per acre in the West region (Table 1), primarily due to regional differences in cotton varieties and in yield.

Table 1. Acreage, Production, and Value of Cotton by Region, 2013-2018 Averages.

Region	Harvested Acreage	Production (Bales of Lint)[6]	Cotton Lint Yield (bales/acre)	Total Value ($1,000)[7]	Gross Revenue ($/acre)
Plains[1]	4,950,000	7,480,000	1.5	2,740,000	$550
Southeast[2]	2,440,000	4,320,000	1.8	1,700,000	$700
Mid-South[3]	1,490,000	3,400,000	2.3	1,380,000	$930
West[4]	390,000	1,230,000	3.2	415,000	$1060
U.S. Total[5]	9,260,000	16,430,000	1.8	6,600,000	$710

Source: USDA/NASS, 2020 (QuickStats). Numbers may not sum due to rounding.
1 Plains: Kansas, New Mexico, Oklahoma, Texas
2 Southeast: Alabama, Florida, Georgia, North Carolina, South Carolina, Virginia
3 Mid-South: Arkansas, Louisiana, Mississippi, Missouri, Tennessee.
4 West: Arizona, California
5 Includes production in "Other States"
6 One bales weighs roughly 480 pounds.
7 Total value includes value of cotton lint as well as cottonseed

DICAMBA-TOLERANT TRAIT ADOPTION

Dicamba-tolerant cotton was developed via genetic modification and was deregulated by the U.S. Department of Agriculture (USDA) in early 2015 (Firko, 2015). DT cotton seed, which is also stacked with glyphosate and glufosinate resistance traits, was available for purchase and use by cotton growers beginning in 2015. However, dicamba for postemergence use was not registered by EPA until after the 2016 growing season (Housenger, 2016). Since DT seed was available in 2015 and 2016, but postemergence dicamba was not available for use until 2017, BEAD considers 2015 and 2016 as transition years for trait adoption and not representative of years where dicamba was a postemergence control option. Therefore, to provide context for dicamba usage, BEAD examines usage of dicamba on cotton varieties prior to introduction of DT traited cotton (in 2013 and 2014) and after the registration of postemergence dicamba for use on DT cotton (in 2017 and 2018). Acres planted with different seed traits before the introduction of the DT trait (2013-2014) and after the introduction of the DT trait (2017-2018) are presented in Table 2.

Table 2. Annual Average Cotton Acres Planted by Seed Trait, 2013-2014 and 2017-2018

Variety	Acres Grown by Trait, 2013-2014	Percentage of Acres Grown by Trait, 2013-2014	Acres Grown by Trait, 2017-2018	Percentage of Acres Grown by Trait, 2017-2018
Conventional / No Herbicide Tolerance	730,000	7%	780,000	6%
Glyphosate-Tolerant	8,630,000	82%	2,210,000	16%
Glufosinate-Tolerant	150,000	1%	0	-
Glufosinate & Glyphosate-Tolerant	1,030,000	10%	1,810,000	16%
Dicamba, Glufosinate and Glyphosate-Tolerant	0	-	7,070,000	56%
2,4-D, Glufosinate, and Glyphosate-Tolerant	0	-	670,000	5%
U.S. Total Cotton Acres	10,550,000		12,540,000	

Source: Kynetec, 2019. Calculations subject to rounding.

According to market research data (Kynetec, 2019), in 2013 and 2014, over 80% of cotton acres were planted with glyphosate-tolerant cotton; the remainder of acres were planted with either conventional cotton or glufosinate and glyphosate-tolerant cotton (Table 2).

Over half of cotton acres planted in 2017-2018 were DT (Table 2). The number of acres planted with conventional cotton is similar across the time periods. Many growers switched from varieties with solely glyphosate tolerance to varieties tolerant to glyphosate as well as other herbicides, including glufosinate, dicamba, and 2,4-D.

While over half of cotton planted in 2017-2018 were DT (Kynetec, 2019), a substantial increase in DT acres was observed year-over-year (Table 2). The USDA Economic Research Service (ERS) also provided information on grower use of DT seed and of dicamba for the 2019 growing season (USDA-ERS, 2020a). ERS data suggests a higher adoption of DT seed compared to market research data. ERS found that in 2019, approximately 69% of U.S. cotton acreage was planted with dicamba-tolerant seed. Letters from the NCC (NCC, 2020a) and the Plains Cotton Growers (Plains Cotton Growers, 2020) also find that 70% of cotton acres planted in 2020 were planted to dicamba-tolerant varieties. Because DT cotton seed adoption appears to be increasing, but BEAD does not have market research data more recent than 2018, the estimates of DT cotton adoption in Table 2 may underestimate current adoption and 70% adoption may be a more realistic estimate.

DICAMBA USAGE IN COTTON PRODUCTION

Dicamba Use by Region

Tables 3a and 3b present usage of dicamba in cotton prior to the introduction of DT traits (2013 and 2014) and after the registration of postemergence dicamba (2017 and 2018). Preemergence dicamba usage in 2017 and 2018 includes both formulations of dicamba intended to be used with DT cotton and formulations of dicamba intended only for preplant burndown use in non-DT cotton. Preemergence dicamba use was low, nationally (7%), before the release of DT cotton (Kynetec, 2019), and concentrated in the Mid-South (Table 3a). With the adoption of DT cotton and the ability to apply dicamba postemergence, as well as the release of dicamba products for use with DT crops, dicamba usage increased nationally, from 7% of cotton acres treated annually with dicamba in 2013-2014 to 43% of cotton acres treated annually with dicamba in 2017-2018.

Total acres treated with dicamba increased from less than 800,000 acres in 2013-2014 (Table 3a) to over 8 million acres in 2017-2018 (Table 3b; Kynetec, 2019). In the same period, pounds of dicamba applied increased by almost a factor of twenty after the introduction of DT cotton and postemergence dicamba, from under 200,000 pounds of dicamba annually in 2013-2014 to over 3.4 million pounds of dicamba annually in 2017-2018 (Kynetec, 2019). At the same time, the average amount of dicamba applied in each application almost doubled, from 0.24 lb/A in 2013-2014 (Table 3a) to 0.41 lb/A in 2017-2018 (Table 3b). The application rate presented in Table 3b is an average of all dicamba formulations. The labels on dicamba products intended for use on DT cotton generally direct higher application rates than labels on products intended for preplant use on non-DT cotton resulting in increased average single application rates after the introduction of DT cotton (Table 3a; Table 3b).

Table 3a. Average Annual Dicamba Usage in Cotton Prior to Release of DT Cotton, 2013-2014

Region [1]	Percent Crop Treated Preemergence [2]	Total Acres Treated [3]	lb Applied	Average Single Application Rate (lb/acre)
Plains	4%	220,000	50,000	0.22
Southeast	3%	100,000	30,000	0.29
Mid-South	34%	460,000	110,000	0.25
West	0%	0	0	-
U.S. Total	7%	780,000	190,000	0.24

Source: Kynetec, 2019. Calculations subject to rounding.

1 See Table 1 for states in each region.

2 Proportion of acres treated at least once with dicamba.

3 Total acres treated accounts for acres treated multiple times. 1 application per acre annually on average.

Table 3b. Average Annual Dicamba Usage in Cotton After Release of DT Cotton, 2017-2018

Region [1]	Percent Crop Treated[2,3]	Total Acres Treated [4]	lb Applied	Average Single Application Rate (lb/acre)
Plains	47%	5,640,000	2,280,000	0.40
Southeast	35%	1,370,000	620,000	0.45
Mid-South	46%	1,380,000	530,000	0.38
West	3%	13,000	7,000	0.53
U.S. Total	43%	8,410,000	3,440,000	0.41

Source: Kynetec, 2019. Calculations subject to rounding.

1 See Table 1 for states in each region.

2 Proportion of acres treated at least once with dicamba.

3 Dicamba usage in 2017 and 2018 Includes both preemergence and postemergence applications. Preemergence applications include both dicamba products intended for use in DT crops and dicamba products intended for preemergence use in non-DT crops.

4 Total acres treated accounts for acres treated multiple times.

Table 3c. Average Annual Dicamba Usage on Cotton by Timing, 2017-2018

Region [1]	Percent Crop Treated Preemergence [2,3]	Percent Crop Treated Postemergence [2]	Percent of Acres Treated Receiving 2 Postemergence Applications[4]	Average Application Rate Pre-emergence (lb/acre)	Average Single Application Rate Post-emergence (lb/acre)
Plains	18%	38%	45%	0.32	0.43
Southeast	5%	32%	47%	0.33	0.46
Mid-South	35%	25%	36%	0.31	0.47
West	0%	3%	0%	-	0.53
U.S. Total	17%	34%	44%	0.32	0.44

Source: Kynetec, 2019. Calculations subject to rounding.

1 See Table 1 for states in each region.

2 Proportion of acres treated at least once with dicamba.

3 Dicamba usage in 2017 and 2018 prior to crop emergence includes both new and older formulations of dicamba.

4 Among acres treated with dicamba after crop emergence, the percentage of acres treated twice with dicamba after crop emergence.

A substantial increase in pounds of dicamba applied annually, and acres of cotton treated annually with dicamba, was observed between 2017 and 2018 (Kynetec, 2019). This increase in usage and acres treated with dicamba matches the increase in adoption of DT seed over the same period (see the section above, Dicamba-tolerant Trait Adoption). Market research data on pesticide usage are not yet available to the EPA for the 2019 production year. Because BEAD does not have market research data more recent than 2018, the estimates in Table 3b may underestimate current dicamba usage.

Dicamba Use by Timing

Prior to the introduction of DT cotton, dicamba use on cotton was limited to preplant use. For non-DT cotton, the preplant restriction (minimum 21 days and 1 inch rainfall) is still applies (BASF, 2020). However, for DT cotton, dicamba products intended for use in DT cotton may be applied up to crop emergence, as well as postemergence. The majority of dicamba, approximately 80% (measured in pounds of active ingredient), was applied to DT cotton (measured in pounds of active ingredient) was applied postemergence (Kynetec, 2019).

Dicamba usage in cotton increased significantly after the introduction of the dicamba-tolerant seed trait. Annual average dicamba use in cotton increased from 190,000 pounds AI (active ingredient) in 2013 to 2014 to over 3.44 million pounds of AI in 2017 to 2018. Over 95% of the dicamba poundage was applied to dicamba-tolerant acres (Kynetec, 2019).

The percent of the cotton crop treated preemergence with dicamba increased from 7% to 17% nationally from 2013-2014 to 2017-2018 (Table 3c). This increase is likely due to the elimination of the preplant restrictions for the dicamba products for use on DT cotton (see the section Benefits of Preemergence Dicamba in Dicamba-Tolerant Cotton).

Nationally, approximately 44% of acres treated with postemergence dicamba applied were treated twice postemergence (Table 3c). The frequency of using two postemergence applications varied across major production regions from 36% in the Mid-South to 47% in the Southeast (Kynetec, 2019).

The average dicamba single application rate increased after the introduction of DT seed (Tables 3a, 3b). This is due to a higher application rate of dicamba being used postemergence as well as higher preemergence application rates (Table 3c). The increase in preemergence rates may be the result of differing label instructions between dicamba products intended for use in non-DT cotton and dicamba products intended for use on DT cotton. Dicamba products intended for use on non-DT cotton allow users of dicamba in cotton to apply up to 0.25 lbs ai/A for preplant burndown control while products intended for use on DT cotton direct users to apply the full labeled rate of 0.50 lbs ai/A for each preemergence application.

BENEFITS OF PREEMERGENCE DICAMBA IN DICAMBA-TOLERANT COTTON

The primary focus of this document is the determination of benefits associated with registration of postemergence dicamba on DT cotton. BEAD recognizes that DT cotton also allows for changes in the preemergence use of these products. The main benefit of this change is increased flexibility in the timing of preemergence dicamba in DT cotton. BEAD qualitatively discusses the benefits of this change in preemergence dicamba use below.

Dicamba products intended for preplant use in non-DT cotton have been labeled for use in cotton prior to planting as part of a fall or spring weed burndown program. Non-DT cotton is sensitive to dicamba, therefore labels for these products specified a planting restriction requiring a specified number of days and amount of rainfall or irrigation water to be accumulated between dicamba application and cotton planting to avoid injury to emerging non-DT cotton seedlings.

These planting restrictions vary by dicamba application rate and formulation, but generally are 21 days between application and cotton planting (BASF, 2020).

The lack of preplanting restrictions on dicamba products intended for use on DT cotton provides a significant benefit to producers, allowing them to include dicamba in their burndown program regardless of their planting schedule. Growers utilizing dicamba products intended for use on non-DT cotton may have to delay planting to comply with the dicamba preplant label restrictions. Since cotton yield is correlated to planting date (Wrather et al., 2007; Boquet and Clawson, 2009), delaying planting can affect cotton yield and thus grower profitability. Since DT cotton is highly tolerant of dicamba there is no need for this preplant restriction for dicamba products intended for use on DT cotton and dicamba can be applied at any time for burndown, preplant, preemergence, and postemergence. Therefore, registering the dicamba products for use on DT cotton would give growers flexibility to use dicamba for weed control at these timings and eliminate the threat of delayed planting due to preplant restrictions.

BENEFITS OF POSTEMERGENCE DICAMBA IN DICAMBA-TOLERANT COTTON

Prior to the introduction of the DT cotton, dicamba could only be used as a preplant application. The primary unique value of the dicamba products which EPA is considering registering is their ability to be used postemergence in DT cotton, and, therefore, the focus of this document is the determination of the benefits of dicamba for postemergence weed control in DT cotton. This section of the document will discuss the weed species likely to be targeted by postemergence dicamba application in cotton, as well as alternative herbicide programs currently available to cotton growers to manage target weed species including herbicide-tolerant weeds. This section will also discuss the quantitative benefits of registering postemergence dicamba in the U.S. and issues related to postemergence dicamba and herbicide resistance.

Target Weeds

Using market research data (Kynetec, 2019), BEAD examined regional postemergence dicamba usage (Table 4) in cotton. In all regions, the main target weeds of postemergence use of dicamba are redroot pigweed and Palmer amaranth. Both are *Amaranthus* species and have similar growth habits, plant morphology and the ability to hybridize. Therefore, BEAD treats them as a single pest when identifying potential herbicides that growers may replace with dicamba.

Table 4: Weeds Targeted with Postemergence Dicamba, Percent of Postemergence-Dicamba-Treated Acres, 2017-2018

Weed	Plains	Southeast	Mid-South	West
Amaranth species	80%	94%	76%	>99%
Redroot Pigweed	*63%*	*60%*	*43%*	*>99%*
Palmer Amaranth	*25%*	*34%*	*36%*	*<1%*

Source: Kynetec, 2019.

Percent is percentage of treatments that were targeted for each pest. Because acres can be treated more than once or treated for multiple pests, numbers may not sum to amaranth species total.

The market survey data are supported by publicly available state agricultural Extension recommendations and information provided by the WSSA. In a 2019 survey of farmers and crop consultants conducted by the WSSA respondents identified pigweed (*Amaranthus*) spp. as the most troublesome weed in cotton. Troublesome weeds refer to those weeds that are most difficult to control regardless of herbicide use or seed technology (VanWychen, 2019). The state Extension weed control guides for Arkansas, Mississippi, Georgia, Tennessee, and Texas cite Palmer amaranth as a target for cotton weed control programs (University of Arkansas, 2020; MSU, 2020; McGinty et al., 2020; Whitaker, 2019; Steckel, 2020c).

Description of Major Herbicide Resistant Target Broadleaf Weeds

One of the main driving forces for the development of DT (and other herbicide-tolerant) cotton varieties was the development of weed populations resistant to multiple herbicide modes of action, primarily glyphosate (WSSA Group 9) and ALS inhibitor herbicides (WSSA Group 2). Both of the *Amaranthus* species in Table 4 have populations that have developed resistance to at least one mode of action and multiple populations that have developed resistance to multiple modes of action. For postemergence herbicidal control to be effective, both Palmer and redroot pigweed need to be treated when small. This fact coupled with the fast growth rate exhibited by these weed species means that the window for control with postemergence herbicides is narrow, which has implications for the herbicide control programs discussed later in this document.

Palmer amaranth

The first herbicide-resistant Palmer amaranth (*Amaranthus palmeri*) population was reported in 1989 in South Carolina (Heap, 2020). In the U.S., there are over 60 Palmer amaranth populations with resistance to at least one herbicide within eight separate modes of action (Heap, 2020). Weed scientists have indicated that dicamba is only effective on Palmer amaranth when they are at or below 2 to 4 inches tall (McGinty et al., 2018). Since Palmer amaranth can grow 2 to 3 inches per day (Sosnoskie et al., 2014), there is a narrow window when applications of dicamba are effective. Cotton yield reductions of up to 60% have been reported with heavy infestations of Palmer amaranth (MacRae et al., 2013).

Redroot Pigweed

The first herbicide-resistant redroot pigweed population was reported in 1995 in Arkansas. In the U.S., there are 19 populations of redroot pigweed with resistance to at least one herbicide within two modes of action (Heap, 2020).

Dicamba Resistance in Dicamba Target Weeds

Dicamba-resistant Palmer amaranth has been confirmed in two states (Tenessee and Kansas) and, state Extension weed scientists have reported decreased Palmer amaranth sensitivity to dicamba in at least five states (Peterson et al., 2019; Barber, 2020; Bradley, 2020; Culpepper, 2020; Steckel, 2020a; Steckel and Perkins, 2020). Resistance occurs over time and can be expected for many pesticides (EPA 2017b). As dicamba resistant weed populations are expected to spread, despite measures being imposed to delay the development of resistance, the benefits of dicamba in DT cotton will decrease over time, although the decreased benefits will be concentrated in areas where dicamba-resistant broadleaf weed species are established. For instance, the University of Tennessee has reported reduced efficacy for Palmer amaranth control for dicamba and downgraded its Palmer amaranth herbicide rating for dicamba (Steckel, 2020c; Steckel, personal communication 2020d).

Available Herbicide Programs for Postemergence Weed Control

One of the main driving factors for the development and use of postemergence dicamba is the prevalence of highly competitive broadleaf weed species, that have developed resistance to many herbicide modes of action, such as glyphosate and ALS inhibitor herbicides, previously used for postemergence weed control in cotton cropping systems.

Given the propensity of certain weed species, such as Palmer amaranth, to develop resistance to multiple herbicide modes of action, the EPA published two Pesticide Registration Notices (EPA, 2017a; EPA 2017b) that closely mirror WSSA guidelines to manage the development of herbicide resistance in weeds and thus preserve currently effective herbicides and herbicide-tolerant crop technologies. The most important and fundamental recommendation is for herbicide programs to utilize at least two effective modes of action per crop for all weeds, taking into account the modes of action that the target weeds have developed resistance to (Norsworthy et al., 2012).

BEAD consulted publicly available state agricultural Extension weed control guides to identify postemergence weed control programs that cotton producers could utilize to effectively control herbicide resistant Palmer amaranth and/or redroot pigweed (*Amaranthus* spp.) (Table 5). BEAD also used these Extension weed control guides to identify a postemergence herbicide program utilizing dicamba. This postemergence dicamba program was compared to the currently available herbicide programs to identify the benefits of registering dicamba for postemergence use in cotton.

The 2020 Weed Control Guidelines for Mississippi (MSU, 2020), and the 2020 Arkansas Recommended Chemicals for Weeds and Brush Control (University of Arkansas, 2020) were used to identify effective herbicides for use in these weed control programs. These guides rate the control of specific target weed species by a certain chemical on a 1 to 10 scale, with 10 representing the highest level of control. BEAD considered herbicides currently available for postemergence herbicide programs and the postemergence dicamba program if the Extension weed control guides indicated the herbicide that would provide rating of at least "8" for Palmer amaranth and/or *Amaranthus* spp. For some herbicides, the weed control guides rated combinations of herbicides (glyphosate + dicamba, glufosinate + 2,4-D, etc.). These combined ratings were considered when developing the herbicide programs used in this analysis. The Extension weed control guides from Tennessee, Georgia, and Texas were also evaluated to confirm the suitability of the herbicides (Whitaker, 2019; McGinty et al., 2020; Steckel, 2020c). While the structure and rating scales of these guides differed from the Mississippi and Arkansas guides, the herbicides and programs recommended were largely similar.

Since the focus of this part of the document is on the benefits of the registration of postemergence dicamba, BEAD also assumed that all existing weeds were removed prior to cotton planting by tillage or burndown herbicide programs. BEAD also assumed that preemergence herbicides containing at least two modes of action (e.g., fluometuron + acetochlor) were applied after planting to provide residual control of problematic weeds prior to postemergence applications.

Previously registered dicamba products intended for use on DT cotton and currently registered Tavium allowed two postemergence applications (EPA, 2018a,b,c), and about 40% of DT cotton acres treated postemergence with dicamba were treated twice (Kynetec, 2019). State agricultural Extension publications generally recommend two postemergence herbicide applications to control *Amaranthus* spp. so both currently available herbicide programs and Dicamba-Tolerant herbicide program presented in Table 5 include two postemergence passes (i.e. applications). However, if the first postemergence application provides adequate weed control until cotton reaches canopy closure, the second postemergence application may not be needed. Therefore, this analysis may overestimate the difference in costs for growers who do not make a second postemergence application.

Table 5: Available Postemergence Herbicide Programs and Dicamba Program for Postemergence Herbicide-Resistant Weed Control in Cotton

	Herbicide 1	Herbicide 2	Herbicide 3	WSSA herbicide modes of actions effective against herbicide-resistant *Amaranthus* spp.[5]
Current Programs[1]				
Glufosinate-Tolerant[2]				
Pass 1	glufosinate	glyphosate	S-metolachlor	Group 10, Group 15
Pass 2	glufosinate	glyphosate	clethodim	Group 10
2,4-D-Tolerant[3]				
Pass 1	glufosinate	2,4-D	S-metolachlor	Group 4, Group 10, Group 15
Pass 2	glufosinate	2,4-D	clethodim	Group 4, Group 10
Alternative Program				
Dicamba-Tolerant[4]				
Pass 1	glyphosate	dicamba	S-metolachlor	Group 4, Group 15
Pass 2	glyphosate	dicamba	clethodim	Group 4

1 Programs based on the 2020 Weed Control Guidelines for Mississippi, and the 2020 Arkansas Recommended Chemicals for Weeds and Brush Control.
2 Utilizes cotton varieties tolerant to both glyphosate and glufosinate
3 Utilizes cotton varieties tolerant to 2,4-D, glyphosate, and glufosinate
4 Utilizes cotton varieties tolerant to dicamba, glyphosate, and glufosinate
5 Group 4: dicamba and 2,4-D; Group 10: glufosinate; Group 15: S-metolachlor

The following section describes each herbicide program scenario used in this assessment and presented in Table 5. The herbicide programs presented below requires the use of the seed that incorporates the appropriate herbicide-tolerance trait. The impact of seed traits on grower costs are discussed in the section "Uncertainties in Cost Comparison."

Glufosinate-Tolerant Program

The Glufosinate-Tolerant program utilizes cotton seed that is resistant to glufosinate and glyphosate (Table 5). Many cotton growers utilize cotton varieties that are resistant to both glyphosate and glufosinate. Glufosinate is a non-selective contact herbicide that provides postemergence control of *Amaranthus* spp that needs to be applied at high spray volume with a medium to coarse droplet size. Like the other herbicides used for postemergence control of

Amaranthus spp. discussed in this document (dicamba and 2,4-D), glufosinate needs to be applied to small *Amaranthus* spp. to achieve adequate postemergence control. Glufosinate has been shown to antagonize the action of glyphosate on grass weeds, potentially resulting in reduced grass control. S-metolachlor is included to provide residual control of later emerging Amaranthus spp. as well as other broadleaf and grass weed species. Clethodim has been included in Pass 2 (Table 5) for this program to remove any grass weeds not controlled by glufosinate, glyphosate, or S-metolachlor. To date, there have been no confirmed cases of weed resistance to glufosinate documented in field crop sites in the U.S (Heap, 2020). However, Extension weed scientists in Arkansas have reported decreased sensitivity of Palmer amaranth to glufosinate (Barber, 2020).

2,4-D-Tolerant Program

The 2,4-D-Tolerant program utilizes cotton seed that is resistant to glyphosate, glufosinate, and 2,4-D (Table 5). Both 2,4-D and glufosinate provide postemergence control of *Amaranthus* spp. and have been shown to be highly efficacious on *Amaranthus* spp. when applied together (MSU, 2020; University of Arkansas, 2020). S-metolachlor has been included to provide residual control of later emerging *Amaranthus* spp, along with grass and other broadleaf weeds. Glufosinate is a contact herbicide and may not provide adequate control of grass weeds. Clethodim has been added in Pass 2 (Table 5) of this program to control any grass weeds not controlled by glufosinate and S-metolachlor. To date there have been no confirmed cases of weed resistance to glufosinate documented in field crop sites in the U.S. However, populations of 2,4-D-resistant Palmer amaranth have been confirmed in Kansas (Heap, 2020).

Dicamba-Tolerant Program

The Dicamba-Tolerant program utilizes seed that is resistant to glyphosate, glufosinate, and dicamba (Table 5). In this program, dicamba provides the postemergence control of *Amaranthus* spp. S-metolachlor has been included in the program to provide residual control of later emerging *Amaranthus* spp., along with grass and other broadleaf weeds. Glyphosate has been included for control of non-herbicide resistant broadleaf and grass weeds. However, dicamba has been shown to antagonize the activity of glyphosate on grass weeds (Steckel, 2020b). Clethodim has been added in Pass 2 of this program to control any weeds not controlled by glyphosate and S-metolachlor. Furthermore, some state Extension weed specialists recommend applying glyphosate separately from dicamba in order to reduce antagonism and improve control of grass weeds which would necessitate a third herbicide pass (Unglesbee, 2019; Pucci, 2020). Similarly, glufosinate has not been included in this program, but a third postemergence pass with glufosinate is recommended in some states (Steckel, 2020a) to control populations of dicamba-resistant weeds or weeds that show reduced sensitivity to dicamba. Populations of dicamba resistant Palmer amaranth have been identified in Kansas and Tennessee and multiple states have reported populations of Palmer amaranth that exhibit reduced sensitivity to dicamba (Barber, 2020; Steckel, 2020a).

Herbicide Resistance Issues in Alternative Programs

BEAD notes that both the 2,4-D Tolerant Program and the Dicamba-Tolerant Program rely on synthetic auxin (WSSA Group 4) herbicides for postemergence control of emerged broadleaf weeds. Previous research and observations have reported cross resistance in weed species to synthetic auxin herbicides (Peterson et al., 2019; Barber, 2020; Steckel, 2020a). Cross resistance occurs when a weed develops a physiological mechanism that makes it resistant to one herbicide (such as dicamba) and that trait also confers resistance to other similar herbicides (such as 2,4-D). Given the threat of cross resistance, the development of weed populations resistant to dicamba could reduce the efficacy of 2,4-D based postemergence herbicide programs (and vice versa) reducing herbicide options available to producers and potentially reducing the benefits of registering dicamba for postemergence use in cotton (Peterson et al., 2019; Barber, 2020; Steckel, 2020a).

Herbicide Control Based on Market Research Data

After the release of DT cotton and the initial registration of postemergence dicamba products in 2016, growers had a new option for postemergence control of problematic weeds. To determine how growers might control herbicide-resistant weeds if dicamba is not registered for use on DT cotton, BEAD examined market research data (Kynetec, 2019) to see what growers who planted DT cotton and used postemergence dicamba in 2017-2018 used for postemergence control in cotton in 2013/2014 (Table 6). According to the data, glyphosate was the most commonly used postemergence herbicide, used on almost every acre. Other commonly used herbicides include acetochlor, glufosinate, and S-metolachlor. From the herbicide use data, it appears that users of postemergence dicamba in 2017-2018 primarily used glyphosate + glufosinate tolerant cotton with glufosinate for postemergence broadleaf control and WSSA Group 15 herbicides (acetochlor, S-metolachlor) for residual control in 2013/2014 (Table 6). While pyrithiobac-sodium and trifloxysulfuron were used on a significant percentage of the acreage, their use was likely targeting other weed species (e.g., morning glory) as both herbicides are ALS inhibitor herbicides (WSSA Group 2) and ALS inhibitor resistance in *Amaranthus* spp. was already widespread in 2013/2014 (Heap, 2020).

Table 6: Herbicides Most Commonly Used Postemergence in 2013 and 2014 by Growers Who Grew DT Cotton and Used Dicamba Postemergence in 2017 and 2018.

Herbicide	Annual Acres Treated with Herbicide[1]	Percent of Acres Treated with Herbicide
Glyphosate	2,820,000	94%
Acetochlor	390,000	24%
Glufosinate	280,000	13%
S-Metolachlor	200,000	12%
Pyrithiobac-Sodium	160,000	9%
Trifloxysulfuron	83,000	5%

Source: Kynetec, 2019. Data from 2013/2014; herbicides included if 5% or more of cotton acres surveyed used herbicide. Acres treated are lower than total acres grown in 2013/2014 since not all growers who were surveyed using DT cotton in 2017-2018 were also surveyed in 2013/2014.
1 Number of acres treated at least once with each herbicide.

BEAD also examined postemergence herbicides used by growers who did not grow DT cotton in 2017-2018 (Table 7). Growers who did not grow DT cotton most frequently applied glyphosate, with the second most commonly applied postemergence herbicide being glufosinate. Other commonly applied herbicides include 2,4-D, acetochlor, and s-metolachlor. These herbicide use data indicate that growers who did not grow DT cotton in 2017 and 2018 used either a glyphosate + glufosinate tolerant herbicide program or a 2,4-D tolerant herbicide program with herbicides such as acetochlor and S-metolachlor providing residual weed control (Table 7).

Table 7: Herbicides Most Commonly Used Postemergence by Growers of Non-DT Cotton in 2017-2018.

Herbicide	Annual Acres Treated with Herbicide[1]	Percent of Acres Treated with Herbicide
Glyphosate	5,780,000	81%
Glufosinate	1,890,000	30%
2,4-D	770,000	11%
Acetochlor	680,000	14%
S-Metolachlor	440,000	9%

Source: Kynetec, 2019. Data from 2017-2018. Acreage includes all cotton acres planted without the DT trait. Herbicides included if 5% or more of cotton acres surveyed used herbicide.
1 Number of acres treated at least once with each herbicide.

Non-Herbicide Weed Control

Preplant conventional tillage can remove emerged problematic weeds before the crop is planted but does not affect weed emergence after the crop emerges. Post planting and postemergence mechanical cultivation is a potential option for control of problematic, herbicide-resistant weeds. However, in-crop cultivation is not able to achieve the same level of control as multiple herbicides and herbicide programs because it can only control weeds between rows and not the weeds within in the row of cotton. Furthermore, travel speeds of in-crop cultivation equipment are slower than the speeds associated with applying herbicides with modern sprayer technology and may require more passes across the field, increasing costs for cotton growers. Also, in-row cultivation is not compatible with narrow row production systems that are beginning to be used parts of the U.S. Given the high costs, relative ineffectiveness of cultivation, and soil conservation concerns BEAD is not considering non-herbicide programs in this document.

Quantitative Benefits of Using Postemergence Dicamba

To determine how growers would respond to the registration of dicamba, BEAD compares grower revenues using currently available programs to the Dicamba-Tolerant Program. BEAD determines the costs of these herbicide programs based on market research data from 2017-2018 (Kynetec, 2019).

BEAD places the changes in herbicide costs into context of grower production using a 2020 cotton production budget from Texas A&M University AgriLife Extension Service (TAMU, 2019). This production budget is for conventionally tilled 24 row dryland GM cotton with an 800 pound yield goal, and uses cotton production budgets from TAMU's District 11, the Coastal Bend District. BEAD chose this budget because District 11 encompasses the most productive cotton county in Texas, San Patricio County, and because the budget has cotton lint yield and cottonseed yield very similar to U.S. national average cotton lint and cottonseed yields (respectively, 900 lbs/A versus 850 lbs/A of cotton lint, and 0.62 tons/A versus 0.55 tons/A of cottonseed) (Table 1). Further, this budget has expected gross revenue very similar to U.S. national average gross revenue ($687/A versus $710/A) (Table 1). BEAD expects the impact of registering postemergence dicamba using this budget to be representative of the impact of registering postemergence dicamba for most of the U.S., excluding high value production in the West region where OTT dicamba was rarely used (Table 3b).

Table 8 shows the cost of the relevant postemergence alternative herbicides according to market research data (Kynetec, 2019). Prices are national averages because target weeds are consistent across regions.

Table 8: Average Per-Acre Per-Application Cost ($/A) of Dicamba and Alternative Postemergence Herbicides, 2017-2018

Chemical	Cost ($/A)
Dicamba	$9
Glyphosate	$4
Glufosinate	$13
2,4-D (Enlist One)	$7
S-metolachlor	$8
Clethodim	$6

Source: Price data from Kynetec (2019). Prices based on postemergence use and average use rates.

Postemergence Dicamba

Due to similarity in target pests, BEAD quantifies the impact of registering dicamba using national average revenues and yields (Table 1). BEAD uses the TAMU budget (2019) to compare production costs. Herbicide costs are based on market research data (Table 8) and Extension recommendations. BEAD calculates that the Dicamba-Tolerant Program may have herbicide costs of $40/A, including an initial application with (Pass 1) glyphosate ($4/A), dicamba ($9/A), and s-metolachlor ($8/A), and a second application (pass 2)glyphosate ($4/A), dicamba ($9/A), and clethodim ($6/A) (Table 5). This herbicide cost is represented in the Dicamba-Tolerant Program column of Table 9 below.

Growers considering using postemergence dicamba may be currently using one of two alternative herbicide programs. Switching from the 2,4-D-Tolerant Program to the Dicamba-Tolerant Program, growers would see a decrease in annual herbicide costs of $14/A, from $54/A to $40/A, equivalent to a 10% increase in net operating revenue (Table 9). Switching from the Glufosinate-Tolerant Program to the Dicamba-Tolerant Program, growers would see an $8/A decrease in herbicide costs, from $48/A to $40/A, equivalent to a 5% increase in grower net operating revenue (Table 9). In both cases, the Dicamba-Tolerant Program reduces grower postemergence herbicide costs relative to the alternative programs. These estimates as a percentage of net operating revenue may overestimate the impact of registering dicamba in regions with higher than average per-acre gross revenue, and may underestimate the impact of registering dicamba in regions with lower than average per-acre gross revenue.

A letter of support from the National Cotton Council (NCC, 2020b) suggests that without dicamba, growers could switch to glufosinate at an increase in herbicide costs of $5/A, but would also suffer from worse control of *Amaranthus* spp. BEAD finds that growers would save more than $5/A with the registration of dicamba. However, based on data from state agricultural Extension weed control guides glufosinate performs at least as well as dicamba for *Amaranthus* spp. control and therefore BEAD expects the alternative herbicide programs utilizing glufosinate will not result in worse control of pigweeds (MSU, 2020; University of Arkansas, 2020).

Table 9: Comparing Per-Acre Impacts on Grower Costs and Net Operating Revenues from Switching to Postemergence Dicamba Programs

	Dicamba-Tolerant Program[6]	**2,4-D-Tolerant Program[7]**	**Glufosinate-Tolerant Program[8]**
Gross Revenue	$710	$710	$710
Postemergence Herbicide Costs	$40	$54	$48
Other Chemical Costs[1,2,3]	$97	$97	$97
Non-Chemical Operating Costs[4]	$345	$345	$345
Seed Cost[5]	$74	$74	$74
Net Operating Revenue	$154	$140	$146
Change in Net Operating Revenue from Switching to Postemergence Dicamba		+$14	+$8
Percent Change in Net Operating Revenue from Switching to Postemergence Dicamba		+10%	+5%

Source: Budgets from TAMU AgriLife Extension Service (2019).
1 Other chemical costs include fertilizer, insecticides, surfactants, plant growth regulators, defoliants, and boll-openers, pre-emergence herbicides, and between-row directed hooded sprayer herbicides.
2 Preemergence herbicides are assumed to be one trip with paraquat and one trip with fluometuron and acetochlor. The cost of this preemergence program is calculated to be $24 per acre (Kynetec, 2019).
3 Between-row directed hooded sprayer herbicides are assumed to be one trip with flumioxazin and MSMA. The cost of this program is calculated to be $12 per acre (Kynetec, 2019).
4 Non-chemical operating costs include preemergence herbicides, fertilizer, custom services, fuel, lube, electricity, repairs, hired labor, and interest on operating capital
5 Seed costs (TAMU, 2019) are average over conventional and GM seeds – budgets do not account for variation in seed costs between herbicide-tolerance traits, or variation in seed costs within herbicide-tolerance traits. Variation in seed costs for any given cotton seed estimated to be $50 or more per acre (FBN 2019; Robinson, 2003).
6 Postemergence herbicides include a first pass with glyphosate, dicamba, and s-metolachlor, and a second pass with glyphosate and dicamba. Herbicide programs described in Table 5 including Pass 1 and Pass 2. Herbicide costs in Table 8.
7 Postemergence herbicides include a first pass with glufosinate, 2,4-D, and s-metolachlor, and a second pass with glufosinate, 2,4-D, and clethodim. Herbicide programs described in Table 5 including Pass 1 and Pass 2. Herbicide costs in Table 8.
8 Postemergence herbicides includes a first pass with glufosinate, glyphosate, and s-metolachlor, and a second pass with glufosinate, glyphosate, and clethodim. Herbicide programs described in Table 5 including Pass 1 and Pass 2. Herbicide costs in Table 8.

Dicamba Resistance and Herbicide Costs

As discussed in the section "Dicamba Resistance in Dicamba Target Weeds" above, Palmer amaranth that is resistant to dicamba has been confirmed in two cotton producing states (Peterson et al., 2019; Steckel, 2020a) and there have been multiple reports of reduced sensitivity of *Amaranthus* spp. to dicamba in other states (Barber, 2020; Culpepper, 2020). If growers using dicamba face dicamba-resistant weeds, some State extension weed scientists recommend a third herbicide pass with glufosinate (Steckel, 2020a). Adding this third pass with glufosinate to the

Dicamba-Tolerant Program above increases postemergence herbicide costs by an additional $13/A (Table 8), from $40/A (Table 9) to $53/A. Growers would also have increased operating costs from the equipment, fuel, and labor required to make a third trip through the field. Facing dicamba-resistant weed pressure, grower herbicide costs are no longer less expensive in the Dicamba-Tolerant Program, and after accounting for increased operating costs, the Dicamba-Tolerant Program may be more expensive than the alternative programs.

Antagonism Between Dicamba and Glyphosate

Dicamba has been shown to antagonize the activity of glyphosate on grass weeds. Some state Extension weed specialists recommend applying glyphosate separately from dicamba in order to reduce antagonism and improve control of grass weeds, which would necessitate a third herbicide pass (Unglesbee, 2019; Pucci, 2020). Growers facing grass pressure who choose to apply glyphosate separately would have increased operating costs from the equipment, fuel, and labor required to make a third trip through the field, though their herbicide costs would not increase. As a result, the Dicamba-Tolerant program may be more expensive for growers facing grass weeds than alternative herbicide programs which do not have antagonism concerns. Growers who are already making a third trip to apply glufosinate for dicamba-resistant weeds would be able to apply glyphosate with glufosinate on the third trip (University of Arkansas, 2020).

Uncertainties in Cost Comparison

In order to apply postemergence glyphosate, glufosinate, dicamba, or 2,4-D growers must purchase seed with the appropriate herbicide-tolerant trait, though seed can be tolerant to multiple herbicides. However, producers consider multiple factors when selecting a cotton variety to plant besides herbicide tolerance traits including yield performance, disease resistance, brand loyalty, and availability in addition to herbicide tolerance. Furthermore, grower costs may be influenced by seller incentive programs and rebates companies may offer growers purchasing seed and herbicides together. Variation in U.S. seed prices can be large – according to the U.S. Seed Price Transparency Report in 2019, in-state price differences of hundreds of dollars per bag for the same variety are observed (FBN, 2019). At 5 acres per bag (Robinson, 2003), this can translate to variation in seed costs of $50 or more per acre. Even though a dicamba program may result in higher grower net revenue on average (Table 9), there could be considerable variation around that average for individual growers due to these variations in seed costs and if rebates are offered. Differences in seed costs and available rebates may be large enough to drive grower decision-making with regards to herbicide choice.

Resistance Management

The registration of dicamba for preemergence and postemergence control of herbicide-resistant broadleaf weeds can be beneficial for herbicide resistance management if used properly. As stated earlier in this document, a key strategy for delaying herbicide resistance in weeds is to utilize at least two effective modes of action in a weed control program. If postemergence dicamba is applied in a control program with other effective modes of action (*e.g.* glufosinate) this can help delay herbicide resistance in both classes of herbicides. However, cotton growers currently have the option to use 2,4-D to control problematic herbicide-resistant weeds in 2,4-D resistant cotton. Since dicamba and 2,4-D have the same herbicidal mode of action (WSSA Group 4) the registration of dicamba for use on DT cotton does not necessarily give growers a new mode of action compared to currently available alternatives, but may give another mode of action to growers unable or unwilling to use 2,4-D-resistant cotton. Multiple dicamba resistant populations of herbicide-resistant Palmer amaranth have been confirmed and state Extension weed scientists have reported resistance to dicamba in Palmer amaranth also confers resistance to 2,4-D (Peterson et al., 2019; Barber, 2020; Steckel, 2020a). As dicamba resistance in problematic weed species, like Palmer amaranth, becomes more widespread the usefulness of both 2,4-D and dicamba as tools for herbicide-resistance management will decline. However, it is difficult to predict exactly where new populations of dicamba-resistant weeds will occur, meaning that impacts to individual growers will vary by location, proximity to existing dicamba-resistant populations, current and past crop production practices, and experience dealing with herbicide-resistant weed species.

CONCLUSIONS

This document describes the benefits of registering dicamba for preemergence and postemergence use on dicamba-tolerant (DT) cotton. $6.6 billion worth of cotton is grown annually on 9.3 million acres each year in the United States. In 2017 and 2018, growers used dicamba on 17% of all U.S. cotton acres (DT and non-DT) prior to crop emergence and on 34% of all U.S. cotton acres after crop emergence. Postemergence dicamba is primarily used to target herbicide-resistant Palmer amaranth and redroot pigweed but is effective at controlling a range of broadleaf weed species.

The dicamba-tolerant system was created to address weed populations with resistance to glyphosate (Weed Science Society of America [WSSA] Group 9 herbicide), ALS (acetolactate synthase) inhibitor herbicides (WSSA Group 2) and PPO (protoporphyrinogen oxidase) inhibitor herbicides (WSSA group 14). The registration of dicamba in DT cotton would give growers additional flexibility in choosing varieties for managing herbicide-resistant weed populations, thereby prolonging the effectiveness of currently available control options for herbicide-resistant weed species. For areas where dicamba products cannot be used on DT cotton, there are effective alternative weed control programs currently available for the control of problematic broadleaf weeds in cotton. However, the number of postemergence herbicide options is very limited; therefore, many cotton growers can benefit from the registration of dicamba for use in DT cotton.

In addition to postemergence application, dicamba in DT cotton has utility prior to crop emergence. Currently registered dicamba formulations include a preplant restriction of a specified number of days and amount of rainfall accumulation between dicamba application and planting to avoid cotton injury. Since DT cotton is highly tolerant of dicamba, the dicamba products intended for use on DT cotton do not include such preplant restrictions, meaning that they can be used at any time up to cotton planting, thereby increasing the flexibility for preemergence dicamba use. This increased flexibility of preemergence use of dicamba on DT cotton is another benefit of the registration of these dicamba products.

Relative to other alternative herbicide programs, a postemergence dicamba program may reduce grower costs by $8-$14 per acre, which may account for 5-10% of grower net operating revenue.

Seed costs and rebates offered by seed and chemical manufacturers can vary widely and affect the overall cost of the herbicide program.

In addition, the further development of dicamba-resistant weed populations would reduce the benefits of this technology in areas where dicamba resistant populations emerge. For example, additional herbicide applications may be necessary to achieve adequate weed control where species are experiencing decreased susceptibility to dicamba, increasing the cost of the postemergence dicamba program relative to alternative herbicide programs. Dicamba-resistant Palmer amaranth have been confirmed in two states. Furthermore, antagonism between glyphosate and antagonism may require growers facing pressure from grass weeds to make additional passes through the field. Risk control measures, discussed in *Dicamba Use on Genetically Modified Dicamba-Tolerant (DT) Cotton and Soybean: Incidents and Impacts to Users and Non-Users from Proposed Registrations* (Chism et al., 2020), may also impinge on the benefits of dicamba, depending on the measure itself.

Overall, BEAD concludes that the registration of dicamba for preemergence and postemergence use in DT cotton gives many growers increased flexibility in their choice of seed varieties. Growers using DT seed have the option to use dicamba as a cost-effective way to control problematic herbicide-resistant broadleaf weed species, and as an additional tool to delay the further development of herbicide resistance.

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